



Small Launch Vehicle (SLV) Concept Development for Affordable Multi-Stage Inline Configurations

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Ben Beers – Vehicle sizing & mass properties

Geocent – Jacobs ESSSA Group, Huntsville, AL, 35806, United States

Eric Waters – Trajectory analysis

Jacobs ESSSA Group, Huntsville, AL, 35806, United States

Alan Philips – Vehicle structural analysis

NASA, George C. Marshall Space Flight Center, AL, 35812, United States

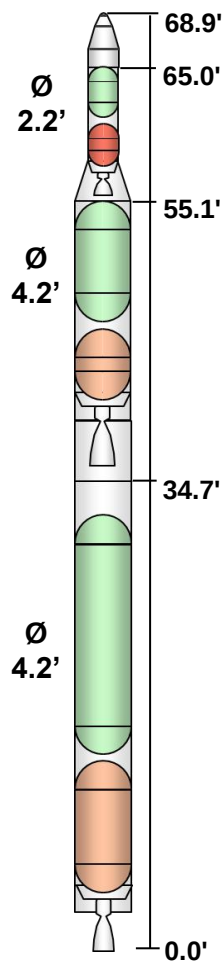
Ed Threet – Team lead

NASA, George C. Marshall Space Flight Center, AL, 35812, United States





Ground Rules & Assumptions



NESC-4A

Item	Stage 1	Stage 2	Stage 3
Propulsion			
Propellants	LOX / RP-1	LOX / RP-1	LOX / RP-1 LCH₄
Mixture ratio, MR	2.77	2.77	2.77
Thrust (lb _f)	55,000	18,000	1,000
Specific impulse, I _{sp} (sec)	300	300	300 360
Propellant feed system type	Pressure-fed	Pressure-fed	Pressure-fed
Propellant tank pressures (psia)	550	550	250
Structures			
Vehicle diameter (ft)	4.17	4.17	2.17
Safety factor	1.4	1.4	1.4
Mass growth allowance, MGA (%)	batt, avionics = 25 all other = 18	batt, avionics = 25 all other = 18	batt, avionics = 25 all other = 18
Vehicle structural material	IM7/877	IM7/877	IM7/877
Trajectory			
Orbit type / delivery altitude (nmi)	Circular / 200		
Inclination (deg)	28.5°		

NESC-1

NESC-4

Both vehicles

← **Standard MGA**

← **Graphite epoxy composite**

Propellant Mass Fraction (PMF)

0.8372

0.8372

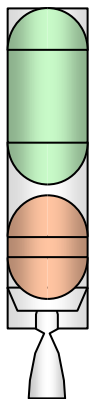
0.8279

0.8293

0.7108

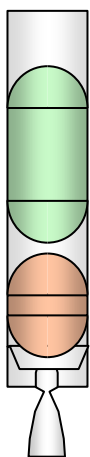
0.6697

Propulsion System Trade Study



Pump-fed system:

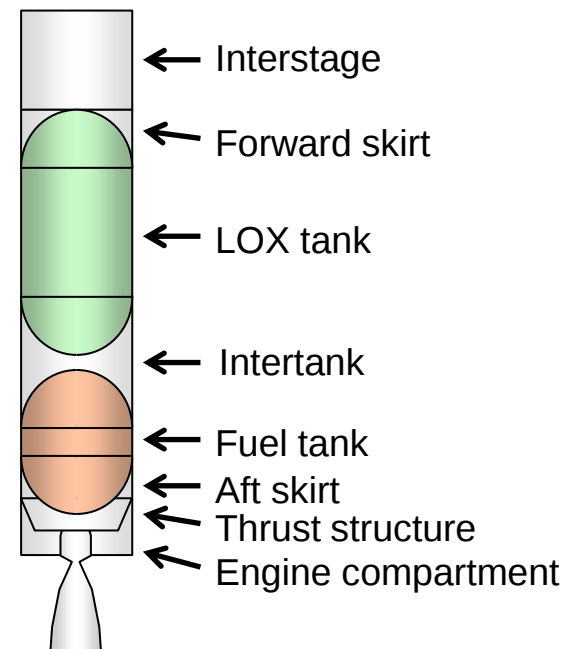
- Low tank pressures
- Small propellant feed system line thickness
- Small pressurant volume accommodations in forward skirt



Pressure-fed system:

- High tank pressures
- Large propellant feed system line thickness
- High pressurant volume accommodations in forward skirt

Structural Safety Factor Sensitivity Study



Key characteristics:

- IM7/877 graphite epoxy composite ($\rho = 0.065 \text{ lb}_m/\text{in}^3$)
- 0.036 in. minimum gauge wall thickness
- 6σ combined worst case loading
- 1% risk of exceeding peak prelaunch wind loads at KSC
- 0.65 structural buckling knockdown factor

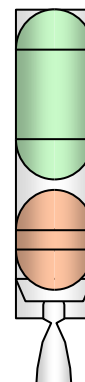
Individual Studies (cont.)

Mass Growth Allowance (MGA) Sensitivity Study

	Standard NESC-4D	NESC-4F	NESC-4G
Avionics & batteries	25%	12.5%	6.25%
All other components	18%	9%	4.5%
Mass savings	N/A	290 lb _m	430 lb _m

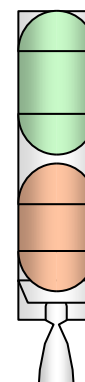
Mixture Ratio (MR) Sensitivity Study

NESC-4F



2.77

NESC-4H



2.50

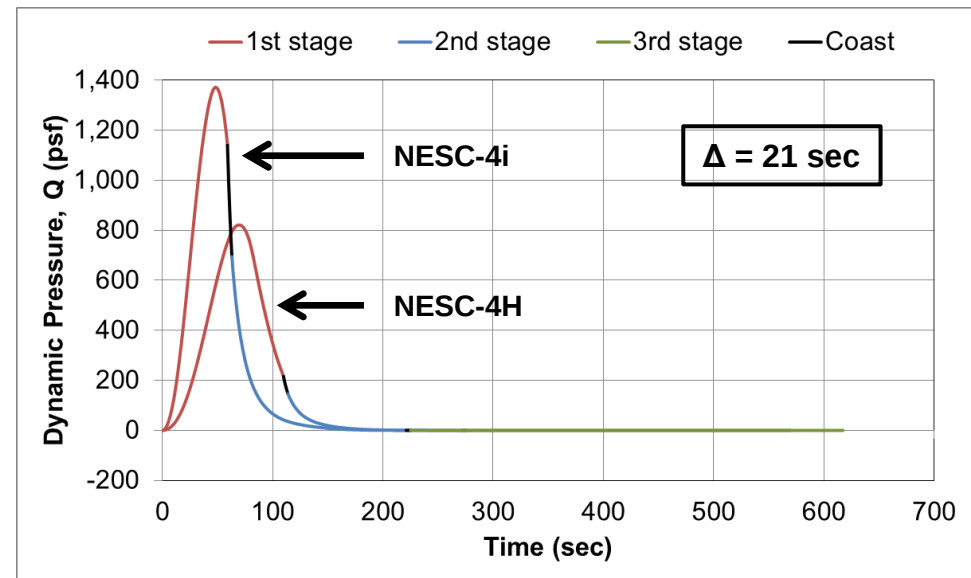
$$MR = \frac{\dot{m}_{oxidizer}}{\dot{m}_{fuel}}$$

Key information:

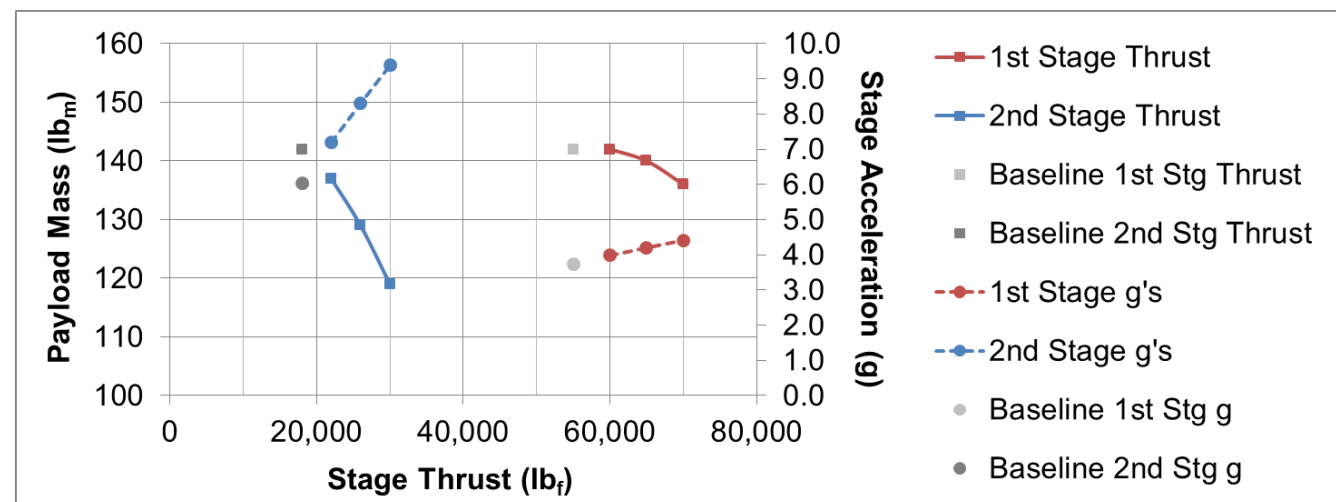
- GLOW was held constant so payload capability was minimally affected.
- MR could be adjusted since rubberized engines were used.

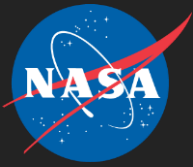
Individual Studies (cont.)

Max Q event at +10 seconds after 1st stage jettison



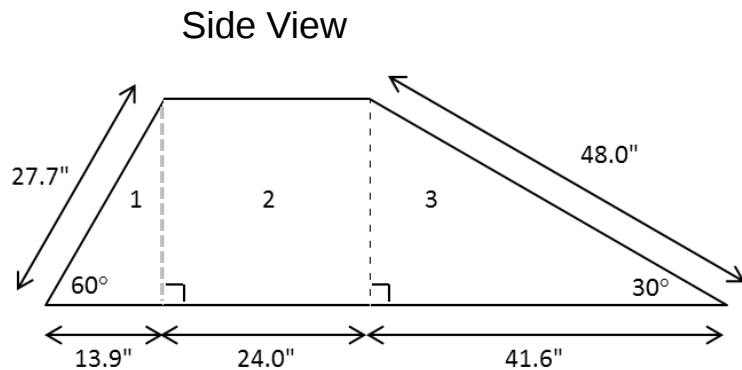
1st and 2nd Stage Thrust Sensitivity Study



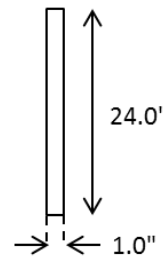


Fin Design

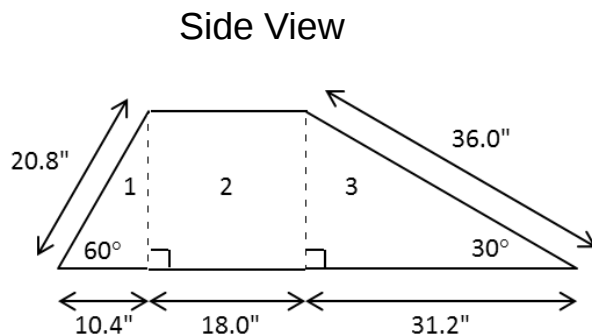
NESC-4Q.1 – 1st stage fin cross section



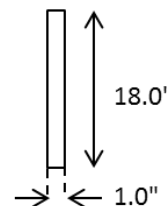
Front View



NESC-4Q.1 – 2nd stage fin cross section



Front View



Item	Stage 1	Stage 2
NESC-4Q.1		
Graphite epoxy composite fins	4	4
Surface area per fin (ft ²)	17.9	10.1
Volume per fin (ft ³)	0.7	0.4
Mass per fin (lb _m)	80.7	45.4
Vehicle stability margin	1.72 (SRBs) 2.13 (no SRBs)	1.21
NESC-4R.1		
Graphite epoxy composite fins	4	4
Surface area per fin (ft ²)	27.9	10.1
Volume per fin (ft ³)	1.1	0.4
Mass per fin (lb _m)	126.0	45.4
Vehicle stability margin	1.64 (SRBs) 3.09 (no SRBs)	1.25

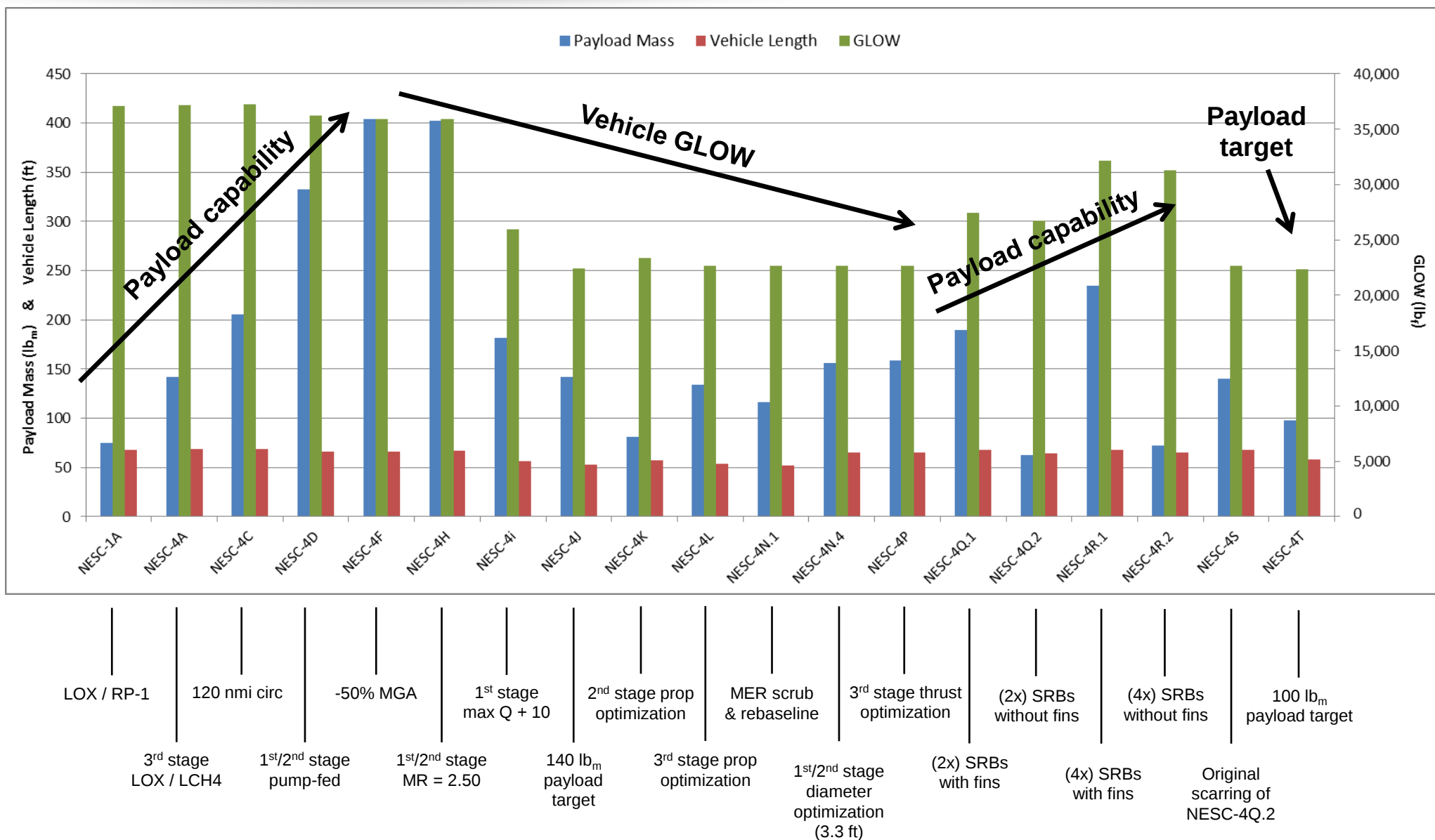
Note: Stability margin rule of thumb is for CG to be forward of CP at ignition by:

- Kick stage ~ 1.5 – 2.0 vehicle diameters
- Subsequent stages ~ 1.0 vehicle diameters

*Mass estimates for NESC-4T include a 0.5 factor for hollow fins for additional savings.

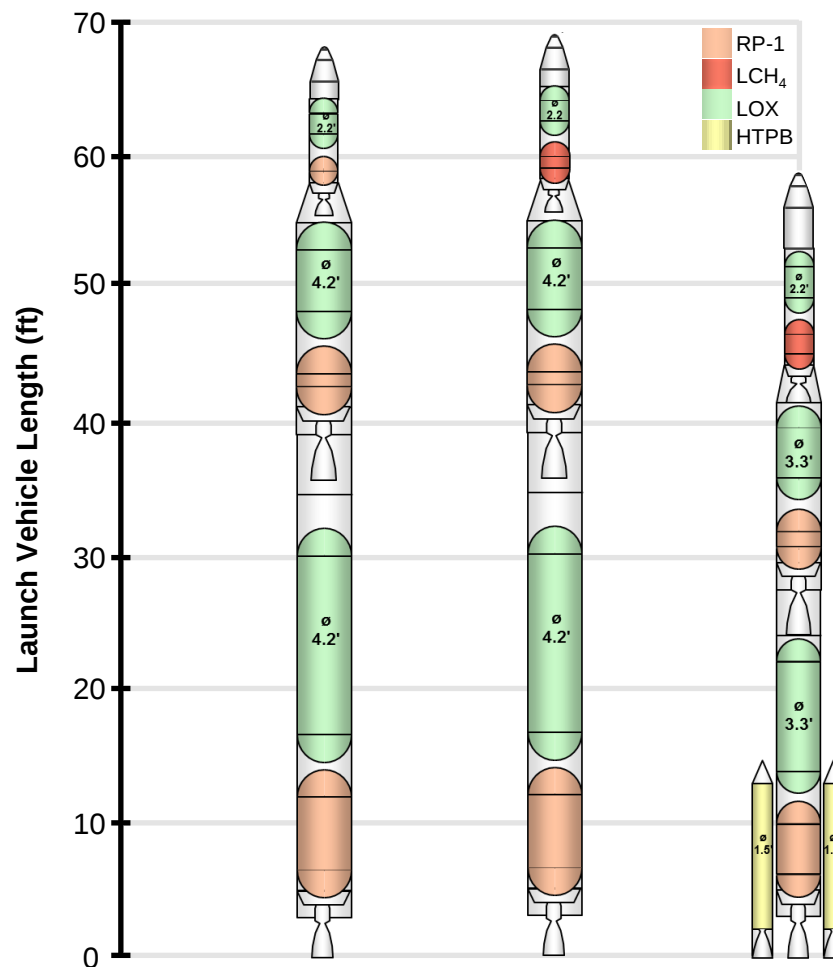


Summary of Results





Vehicle Comparisons



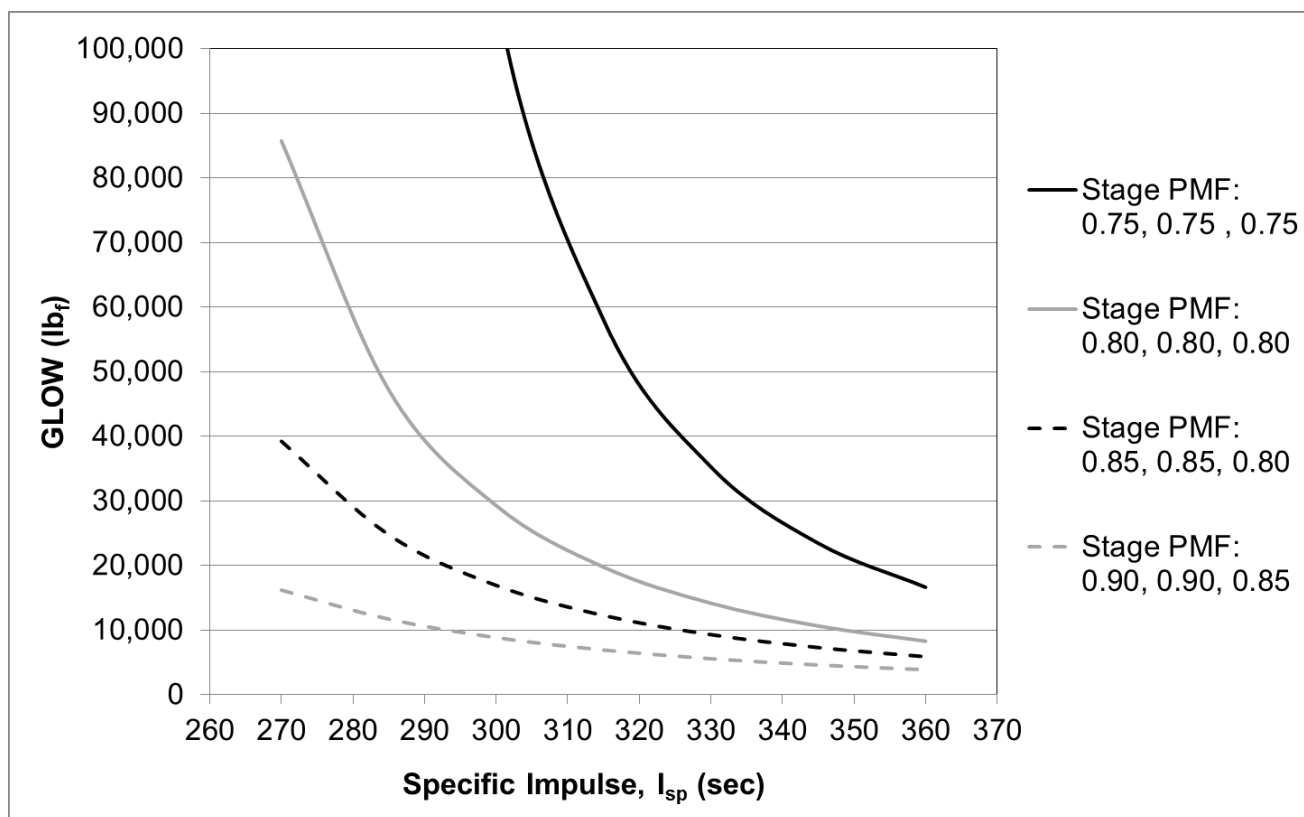
Configuration	NESC-1	NESC-4	NESC-4T
GLOW (lb _f)	37,133	37,187	22,378
LEO Payload (lb _m)	75	142	98
Delivery Orbit (nmi)	200 circ	200 circ	120 circ



BACK-UP SLIDES



SLV Trade Space Sizing Tool





NESC 1 Sensitivity Study Summary

■ = parent vehicle

↓ / ↑ = with reference to parent vehicle

Group	Sensitivity Study	GLOW (lb _f)	Veh. Length (ft)	Payload (lb _m)
■ NESC-1A	Baseline ground rules and assumptions	37,133 —	68.1 —	75 —
├─ NESC-1A	1 st stage $I_{sp} = +10$ sec (310 sec)	37,149 ↑	68.1 —	91 ↑
├─ NESC-1A	1 st stage $I_{sp} = -10$ sec (290 sec)	37,118 ↓	68.1 —	60 ↓
├─ NESC-1A	2 nd stage $I_{sp} = +10$ sec (310 sec)	37,160 ↑	68.1 —	102 ↑
├─ NESC-1A	2 nd stage $I_{sp} = -10$ sec (290 sec)	37,108 ↓	68.1 —	50 ↓
├─ NESC-1A	3 rd stage $I_{sp} = +10$ sec (310 sec)	37,157 ↑	68.1 —	99 ↑
├─ NESC-1A	3 rd stage $I_{sp} = -10$ sec (290 sec)	37,109 ↓	68.1 —	51 ↓
├─ NESC-1A	1 st stage PMF = +0.02 (0.8573)	36,586 ↓	68.1 —	91 ↑
├─ NESC-1A	1 st stage PMF = -0.02 (0.8171)	37,707 ↑	68.1 —	59 ↓
├─ NESC-1A	2 nd stage PMF = +0.02 (0.8480)	36,909 ↓	68.1 —	123 ↑
├─ NESC-1A	2 nd stage PMF = -0.02 (0.8078)	37,375 ↑	68.1 —	32 ↓
├─ NESC-1A	3 rd stage PMF = +0.02 (0.7308)	37,134 ↑	68.1 —	114 ↑
├─ NESC-1A	3 rd stage PMF = -0.02 (0.6908)	37,133 —	68.1 —	34 ↓
■ NESC-4A	Baseline ground rules and assumptions	37,187 —	68.9 —	142 —
├─ NESC-4A	1 st stage $I_{sp} = +10$ sec (310 sec)	37,205 ↑	68.9 —	162 ↑
├─ NESC-4A	1 st stage $I_{sp} = -10$ sec (290 sec)	37,170 ↓	68.9 —	125 ↓
├─ NESC-4A	2 nd stage $I_{sp} = +10$ sec (310 sec)	37,217 ↑	68.9 —	172 ↑
├─ NESC-4A	2 nd stage $I_{sp} = -10$ sec (290 sec)	37,159 ↓	68.9 —	114 ↓
├─ NESC-4A	3 rd stage $I_{sp} = +10$ sec (370 sec)	37,209 ↑	68.9 —	163 ↑
├─ NESC-4A	3 rd stage $I_{sp} = -10$ sec (350 sec)	37,166 ↓	68.9 —	121 ↓



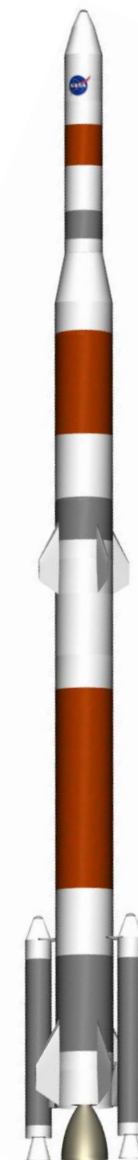
NESC 4 Sensitivity Study Summary (cont.)

■ = parent vehicle

↓ / ↑ = with reference to parent vehicle

Group	Sensitivity Study
NESC-4A	1 st stage PMF = +0.02 (0.8573)
NESC-4A	1 st stage PMF = -0.02 (0.8171)
NESC-4A	2 nd stage PMF = +0.02 (0.8494)
NESC-4A	2 nd stage PMF = -0.02 (0.8093)
NESC-4A	3 rd stage PMF = +0.02 (0.6897)
NESC-4A	3 rd stage PMF = -0.02 (0.6497)
NESC-4B	160 nmi circular orbit altitude
NESC-4C	120 nmi circular orbit altitude
NESC-4D	1 st and 2 nd stage pump-fed propulsion systems
NESC-4E	Vehicle structural safety factor = 1.2
NESC-4F	50% MGA allowable (12.5% batt, avionics; 9% all other)
NESC-4G	25% MGA allowable (6.25% batt, avionics; 4.5% all other)
NESC-4H	1 st and 2 nd stage LOX / RP-1 MR = 2.50
NESC-4i	1 st stage propellant reduction for burnout at max Q +10 sec
NESC-4J	2 nd stage propellant reduction targeting 140 lb _m payload
NESC-4J	2 nd stage thrust = +4,000 lb _f (22 klb _f)
NESC-4J	2 nd stage thrust = +8,000 lb _f (26 klb _f)
NESC-4J	2 nd stage thrust = +12,000 lb _f (30 klb _f)
NESC-4J	1 st stage thrust = +5,000 lb _f (60 klb _f)
NESC-4J	1 st stage thrust = +10,000 lb _f (65 klb _f)
NESC-4J	1 st stage thrust = +15,000 lb _f (70 klb _f)

GLOW (lb _f)	Veh. Length (ft)	Payload (lb _m)
36,644 ↓	68.9 –	161 ↑
37,758 ↑	68.9 –	124 ↓
36,971 ↓	68.9 –	195 ↑
37,421 ↑	68.9 –	94 ↓
37,188 ↑	68.9 –	184 ↑
37,187 –	68.9 –	99 ↓
37,223 ↑	68.9 –	177 ↑
37,252 ↑	68.9 –	206 ↑
36,196 ↓	66.4 ↓	333 ↑
36,189 ↓	66.4 –	336 ↑
35,907 ↓	66.4 –	404 ↑
35,764 ↓	66.4 –	441 ↑
35,918 ↑	67.1 ↑	402 ↓
25,966 ↓	56.0 ↓	182 ↓
22,436 ↓	53.3 ↓	142 ↓
23,516 ↑	53.3 –	137 ↓
23,585 ↑	53.3 –	129 ↓
23,651 ↑	53.3 –	119 ↓
23,470 ↑	53.3 –	142 –
23,504 ↑	53.3 –	140 ↓
23,538 ↑	53.3 –	136 ↓



NESC-4Q.1



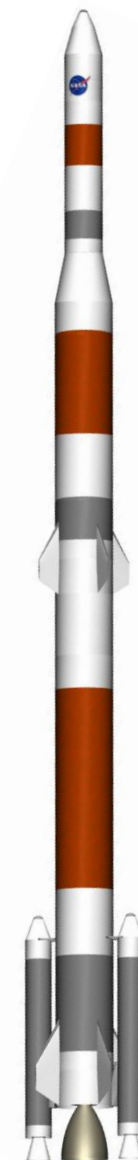
NESC 4 Sensitivity Study Summary (cont.)

■ = parent vehicle

↓ / ↑ = with reference to parent vehicle

Group	Sensitivity Study
NESC-4K	2 nd stage RP-1 tank dome-to-dome, propellant moved to 3 rd stage
NESC-4L	3 rd stage propellant load (and payload) optimization
NESC-4N	MERs scrubbed and model rebasined
NESC-4N	1 st and 2 nd stage vehicle diameter = -0.17 ft (4.0 ft)
NESC-4N	1 st and 2 nd stage vehicle diameter = -0.32 ft (3.85 ft)
NESC-4N	1 st and 2 nd stage vehicle diameter = -0.87 ft (3.30 ft)
NESC-4o	2 nd stage thrust = -2,000 lb _f (16 klb _f)
NESC-4o	2 nd stage thrust = -4,000 lb _f (14 klb _f)
NESC-4o	2 nd stage thrust = +2,000 lb _f (20 klb _f)
NESC-4P	3 rd stage thrust = +200 lb _f (1.2 klb _f)
NESC-4Q.1	+2 SRBs, 1 st /2 nd stage passive guidance systems, rail launch
NESC-4Q.2	+2 SRBs, 1 st /2 nd stage active guidance systems, tower launch
NESC-4R.1	+4 SRBs, 1 st /2 nd stage passive guidance systems, rail launch
NESC-4R.2	+4 SRBs, 1 st /2 nd stage active guidance systems, tower launch
NESC-4S	Original scarring of NESC-4Q.2
NESC-4T	100 lb _m payload target

GLOW (lb _f)	Veh. Length (ft)	Payload (lb _m)
23,352 ↑	57.2 ↑	81 ↓
22,675 ↓	53.6 ↓	134 ↑
22,672 ↓	52.3 ↓	116 ↓
22,647 ↓	54.4 ↑	125 ↑
22,634 ↓	56.1 ↑	134 ↑
22,656 ↓	65.6 ↑	156 ↑
22,614 ↓	65.6 —	154 ↓
22,562 ↓	65.6 —	148 ↓
22,703 ↑	65.6 —	154 ↓
22,674 ↑	65.6 —	159 ↑
27,417 ↑	67.8 ↑	190 ↑
26,718 ↑	64.1 ↓	63 ↓
32,169 ↑	68.3 ↑	235 ↑
31,275 ↑	64.9 ↓	72 ↓
22,675 ↓	67.8 ↑	140 ↑
22,378 ↓	58.0 ↓	98 ↓



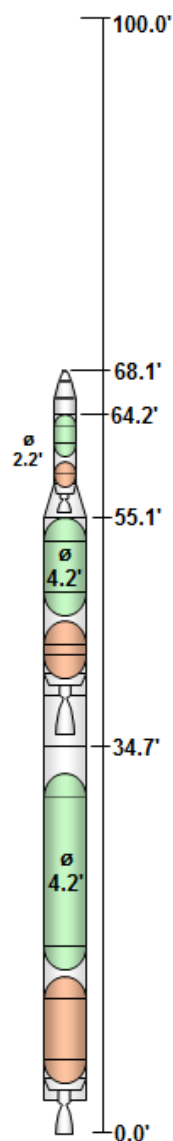
NESC-4Q.1



NESC 1A (baseline)

<u>Interstage</u>	Second/Third
Dry Mass	33 lbm
<u>Third Stage</u>	
Propellants	LOX / Jet-A
Nominal Ascent Propellant	1,012 lbm
Stage pmf	0.7108
Dry Mass	360 lbm
Burnout Mass	412 lbm
# Engines	1
Engine Thrust (100.0%)	1,000 lbf @ Vac
Engine Isp (100.0%)	300.0 sec @ Vac
Stage Burn Time	303.9 sec

<u>Delivery Orbit</u>	
LEO Delivery	200.0 x 200.0 nmi @ 28.5°
LEO Gross Payload	75 lbm (34.0 kg)
Insertion Altitude	200.0 nmi
T/W @ Liftoff	1.37
Max Dynamic Pressure	714 psf
Max g's Ascent Burn	5.14
T/W @ 2nd Stage Ignition	1.34
T/W @ 3rd Stage Ignition	0.67



<u>GLOW</u>	37,133 lbf
Shroud Jettison Mass	47 lbm

<u>First Stage</u>	
Propellants	LOX / Jet-A
Total Stage Ascent Propellant	20,133 lbm
Stage pmf	0.8372
Dry Mass	3,448 lbm
Burnout Mass	3,915 lbm
# Engines	1
Engine Thrust (100.0%)	55,000 lbf @ Vac
Engine Isp (100.0%)	300.0 sec @ Vac
Mission Power Level	100.0%
Stage Burn Time	109.8 sec

<u>Interstage</u>	First/Second
Dry Mass	52 lbm

<u>Second Stage</u>	
Propellants	LOX / Jet-A
Nominal Ascent Propellant	9,482 lbm
Stage pmf	0.8279
Dry Mass	1,720 lbm
Burnout Mass	1,971 lbm
# Engines	1
Engine Thrust (100.0%)	18,000 lbf @ Vac
Engine Isp (100.0%)	300.0 sec @ Vac
Stage Burn Time	158.0 sec

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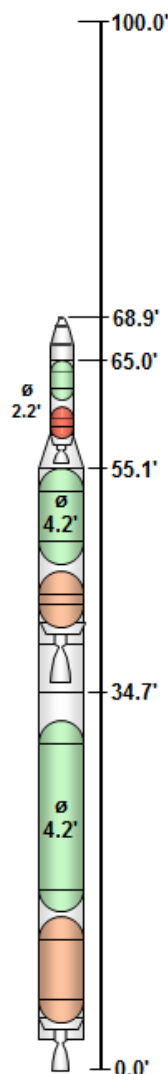
JBH / ED04

NESC 1A



NESC 4A (baseline)

Interstage	Second/Third
Dry Mass	35 lbm
Third Stage	
Propellants	LOX / LCH ₄
Nominal Ascent Propellant	957 lbm
Stage pmf	0.6697
Dry Mass	420 lbm
Burnout Mass	472 lbm
# Engines	1
Engine Thrust (100.0%)	1,000 lbf @ Vac
Engine Isp (100.0%)	360.0 sec @ Vac
Stage Burn Time	344.5 sec
Delivery Orbit	
LEO Delivery	200.0 x 200.0 nmi @ 28.5°
LEO Gross Payload	142 lbm (64.5 kg)
Insertion Altitude	200.0 nmi
T/W @ Liftoff	1.36
Max Dynamic Pressure	717 psf
Max g's Ascent Burn	5.06
T/W @ 2nd Stage Ignition	1.33
T/W @ 3rd Stage Ignition	0.64



GLOW	37,187 lbf
Shroud Jettison Mass	48 lbm
First Stage	
Propellants	LOX / Jet-A
Nominal Ascent Propellant	20,133 lbm
Stage pmf	0.8372
Dry Mass	3,448 lbm
Burnout Mass	3,916 lbm
# Engines	1
Engine Thrust (100.0%)	55,000 lbf @ Vac
Engine Isp (100.0%)	300.0 sec @ Vac
Mission Power Level	100.0%
Stage Burn Time	109.8 sec
Interstage	First/Second
Dry Mass	52 lbm
Second Stage	
Propellants	LOX / Jet-A
Nominal Ascent Propellant	9,482 lbm
Stage pmf	0.8293
Dry Mass	1,700 lbm
Burnout Mass	1,952 lbm
# Engines	1
Engine Thrust (100.0%)	18,000 lbf @ Vac
Engine Isp (100.0%)	300.0 sec @ Vac
Stage Burn Time	158.0 sec

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NESC 4A



NESC 4T (100 lb_m target)

Third Stage

Propellants	LOX / LCH ₄
Nominal Ascent Propellant	1,227 lbm
Stage pmf	0.6986
Dry Mass	447 lbm
Burnout Mass	529 lbm
# Engines	1
Engine Thrust (100.0%)	1,200 lbf @ Vac
Engine Isp (100.0%)	360.0 sec @ Vac
Stage Burn Time	368.0 sec

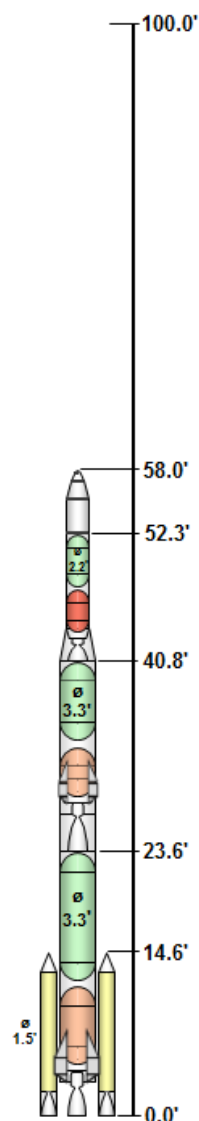
Solid Booster (each)

Casing Type	
Propellants	
Overboard Propellant	
Stage pmf	
Burnout mass	
# Boosters	
Average Thrust @ 70 °F	
Stage Burn Time	

Delivery Orbit

LEO Delivery	120.0 x 120.0 nmi @ 28.5°
LEO Gross Payload	98 lbm (44.5 kg)
Insertion Altitude	120.0 nmi
T/W @ Liftoff	1.85
Max Dynamic Pressure	2,120 psf
Max g's Ascent Burn	8.68
T/W after SRB separation	1.91
T/W @ 2nd Stage Ignition	1.67
T/W @ 3rd Stage Ignition	0.62

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GLOW

Shroud Jettison Mass	22,378 lbf
	88 lbm

First Stage

Propellants	LOX / Jet-A
Nominal Ascent Propellant	8,060 lbm
Stage pmf	0.7953
Dry Mass	1,935 lbm
Burnout Mass	2,075 lbm
# Engines	1
Engine Thrust (100.0%)	45,700 lbf @ Vac
Engine Isp (100.0%)	300.0 sec @ Vac
Mission Power Level	100.0%
Stage Burn Time	52.9 sec

Interstage

Dry Mass	First/Second
	43 lbm

Second Stage

Propellants	LOX / Jet-A
Nominal Ascent Propellant	4,916 lbm
Stage pmf	0.8238
Dry Mass	959 lbm
Burnout Mass	1,051 lbm
# Engines	1
Engine Thrust (100.0%)	14,350 lbf @ Vac
Engine Isp (100.0%)	300.0 sec @ Vac
Stage Burn Time	102.8 sec

Interstage

Dry Mass	Second/Third
	29 lbm

NESC 4T

